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A PERSPECTIVE ON PROCEDURAL MODELING BASED ON STRUCTURAL ANALYSIS

UNA PERSPECTIVA SOBRE MODELADO PROCEDURAL BASADO EN ANALISIS ESTRUCTURALES

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Abstract:

We introduce a study focused on procedural modeling papers that use methods of structural analysis, especially in its application to historic buildings such as churches and cathedrals. Moreover, we have taken a geometric structure of one of these papers and studied their behavior in a generic simulation tool, thus showing the feasibility of its analysis with non-specialized tools.

Key words: procedural modeling, virtual historical buildings, masonry structures, stable structures.

Resumen:

Introducimos un estudio centrado en aquellos trabajos de modelado procedural que utilizan métodos de análisis estructural, especialmente en su aplicación para edificios históricos como iglesias y catedrales. Por otra parte, hemos tomado una estructura geométrica de uno de estos artículos y estudiado su comportamiento en una herramienta de simulación genérica, mostrando su factibilidad para realizar análisis con herramientas no especializadas.

Palabras clave: modelado procedural, edificios históricos virtuales, estructuras de ladrillos, estructuras estables.

1. Introduction

Modeling urban environments is becoming popular in computer graphics research for application software. Recently, some researchers have found some ways to explore methodologies that combine visual results with structural analysis, especially on masonry structures. For this reason, we have focused our perspective analysis on this kind of methodologies with the aim of knowing their influence in the virtual environment creation. Thus, this paper describes an open perspective with the most suitable techniques for research about procedural modeling based on the structural stability studies, masonry structures and especially in those religious buildings built on the middle ages. Moreover, we made a structural analysis of feasibility, through a freely physical simulator tool, of a geometrical structure provided by one of these works (Panozzo *et al.* 2013), which was obtained after a sound procedural methodology.

2. Perspective on Procedural Modelling

This section discusses about procedural modeling techniques that are suitable for modeling buildings.

2.1. Procedural Modelling

Müller *et al.* (2006) presented a methodology based on the concept of a shape grammar, which is based on a base rule called seed; with an iterative application of transforming rules. Each rule starts with the specification of a label, called predecessor, where an input shape (part of a building) is selected, and then the rules themselves, called successors, change the geometry and, consequently, the shape of the building. Indeed, when we add a new rule successor to a given predecessor, we are actually creating a graph of rules (Patow 2012). Recently, Kelly and Wonka (2011) introduced a methodology where the concept of a generalized extrusion is applied on a building through a set of profiles. Talton *et al.* (2011) describe a methodology where a Markov Chain Monte Carlo system is used to create variations on a given rule set, and apply their technique to complex structures like vegetation or buildings. Later, Musialski, Wimmer and Wonka (2012), based their work on an interactive framework that use images for the building facade modeling. Following a similar approach, Krecklau and Kobbelt (2012) created a tool designed for ordinary users without any programming knowledge that manipulates the procedural grammars in a transparent way when a building is created or modified. Although,

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the methodologies presented represent a great advance, they still pose some problems for the non-expert users. In that line, some researchers presented visual editing systems, like the one described by Patow (2012), or the one simultaneously developed by Procedural, now part of Esri, for their CityEnigne system (City Engine 2016). Moreover, these works described above, have ignored any sort of structural problems, crucial for ancient buildings like churches. This is the main reason because we will focus in those works based on structural analysis tools too.

2.2. Structural Masonry Buildings

Whiting *et al.* (2009) introduced one of the first works to describe a method based on masonry structures such as cathedrals or stone bridges, for procedural modeling. Following the previous work, Whiting (2011) presented an extension with a new set of methods for allowing the study of the building soundness through the integration of architecture design and structural analysis. Recently, Whiting *et al.* (2012) introduced a method to analyze a given masonry building geometry through their vertex coordinates. Once the geometry is loaded, the aim of the method is to create a new stable structure through the analysis of the stability gradient, according to constraints previously introduced by the user. Following another way, Panozzo *et al.* (2013), introduced an algorithm that does not require any structural knowledge from users because it automatically generates a 3D masonry structure from an input shape (an input patch, like a NURBS surface) and a given height. Later on, *Deuss et al.* (2014), introduced a new algorithm that processes all kind of masonry models, from historical buildings to free-form ones. Initially, it takes a masonry structure built in rigid blocks and transforms this into an ordered sequence, where each block can be added to the construction process by the use and placement of chains and hooks.

3. Static Study of a Masonry Structure

In the medieval period, a critical key stage for the construction of cathedrals was the vault. In that time, a trial and error brick fitting procedure was used, allowing them to build vaults without mortar because the vault self-supported its weight through friction. Following a similar reasoning, we have taken a model for our structural tests, the vault from the work of Panozzo *et al.* (2013). To perform the structural tests of this vault, we have chosen freely available commercial software like Houdini from SideFX (2016) and the open source Bullet solver (incorporated by default in Houdini). Moreover, we have built the geometry that supports the masonry vault. So, with the aim of building a structure that resembling a Romanesque church, we built three supporting walls of voussoirs (blocks) with a width of 2 meters. Given this basic structure, we placed the imported vault geometry (Panozzo *et al.* 2013) on top of it. In this case, the voussoirs were added without mortar among them, following Panozzo et al.'s specifications (Fig. 1).

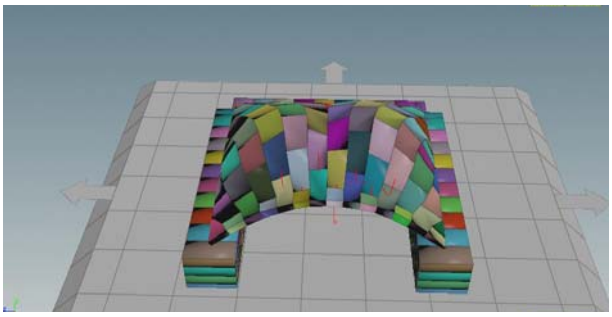

Figure 1: Our vault over the walls that simulate a Romanesque church.

At this point, we have run our structural simulation. As a result of it, we can observe that the vault collapses. In order to improve stability, we adjusted (increased) the value of the so called “rotational stiffness” for the vault until it worked in the simulation. At this point, we begin reducing the width of the walls until 1.5m in an iterative way. We found out that the vault supports their weight with the new wall parameters, but we observed a few cracks (in our case, represented by some loose stones) on the walls. We continued decreasing the walls width until a value of 1.2 m, where the number of the cracks on the walls increased, as expected. Beyond this point, the whole structure would fall into pieces then, we added buttresses to the entire structure obtaining better results: the vault now supported its own weight and the walls did not show any damage in their structure. At this point, we decided to reduce the width of our walls again, until 0.5m. With these wall parameters, we still obtained good results for the structure (i.e., the vault and the walls).

4. Perspective Work

With the previous analysis, we have obtained a basis for following the research about procedural modelling in the context of sound masonry structures. Also, we plan to focus on the construction, structure, form and general evolution of masonry buildings, like medieval churches.

5. Conclusions

We have reviewed the state-of-the-art literature on techniques involving procedural modeling tools that incorporate soundness analysis. From this analysis we found that only a handful of papers deal with this complex, but crucial aspect of modeling. As part of an ongoing experimental study, we have tested the statics of a structure that combines the geometry of the walls and an imported vault where the methodology proposed by Panozzo *et al.* (2013), have been validated under different simulation conditions.

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